

DISCUSSION ON GLACIOLOGICAL RESEARCH
IN THE ANTARCTIC

held at the Department of Geography, Cambridge on the 14 May 1947 (see p. 92)

The Reverend W. L. S. FLEMING (Chairman): Members will already know the way in which this meeting originated. The recently formed Joint Polar Research Committee of the Royal Geographical Society and the Scott Polar Research Institute asked this Society to submit a general programme of promising fields of research in the Antarctic. A discussion of a somewhat similar nature was held in July 1939 after Professor F. Alton Wade had suggested that the Society, then known as the Association for the Study of Snow and Ice, should make suggestions for glaciological research for the United States Antarctic Service Expedition, 1939-41. This discussion was reported in the Society's records, *Papers and Discussions*, in September 1939. Professor Wade has published the results of the expedition and states that the glaciological programme was based on the proposals submitted by the Society. It is therefore hoped that this meeting, too, will be useful for future work on glaciology in the Antarctic.

Although we are limiting our discussion to the Antarctic, clearly the problems will also apply to the Arctic and other glacierized regions.

With regard to procedure, we will follow the list of subjects which was sent to members. This is divided into seven main divisions: Snow, Glaciers (General), Glaciers (Climatological), Shelf Ice, Sea Ice, Glacial Geomorphology and General. Under each of the main headings are sub-headings, and I shall read them out so that we can discuss them point by point. In preparing these sub-headings it was not implied that each should necessarily be discussed, nor were the headings regarded as exclusive. At the end of each main heading an opportunity will be given to discuss points which have not been listed.

It would be helpful if speakers would indicate the significance of their comments and avoid speculative discussion as far as possible.

A. SNOW

1. *Nature of Antarctic snow cover. Comparison with other regions. Grain size and specific gravity. Frequency and mode of origin of true ice (sp. gr. 0.82 and greater)*

No comments.

2. *Regime of snow cover summer and winter. Change of snow level. Precipitation*

Mr. L. C. W. BONACINA (communicated): The origin of the Antarctic precipitation is a very important question for investigation. I think it highly probable that the chief factor is the passage of frontal movements in association with the Southern Ocean cyclones, sufficiently close to the Antarctic continent to cause considerable snowfalls. These frontal passages should be linked up with the pressure-waves which Sir George Simpson postulated to account for severe localized blizzards. Professor Hobbs' theory, that the Antarctic snowfall is mainly due to a kind of snow-drizzle sublimating near the surface of the ice sheet from a glacial anticyclone, is almost certainly erroneous, as has recently been shown by Matthes in the case of Greenland. Many years ago I inferred that Greenland must receive heavy cyclonic snowfall from the mere fact that its southern extremity lies close to the Icelandic locus of mean low pressure. This signifies influence by a constant succession of depressions and cyclonic storms.

Dr. C. E. P. BROOKS (Meteorological Office, Air Ministry): A fundamental basis for the study of the origin of snow in the Antarctic is a knowledge of the distribution of the depth of annual snowfall. The problem of measuring the depth of fresh snowfall, as opposed to re-deposited drift, by means of a rain or snow gauge has not, so far as I know, been solved. Even in this country measurements are unsatisfactory when there is much wind.

Mr. L. G. DOBBIE (Australian Scientific Research Liaison): For our purposes (Australia) and for the general problem of the heat and ice balance of the continent, it is required to measure not only the local rate of deposit of snow on the surface, but also to measure separately the falling precipitation and the drifting snow. The glaciologists may be aware of special techniques which have been developed for this purpose, and, if so, we would like to have details.

Mr. G. SELIGMAN: The Swiss have done a great deal of work on this subject and I will endeavour to obtain the latest information during my forthcoming visit to Switzerland. I strongly recommend, in the meantime, that any expedition desiring to measure snowfall during blizzards, should consult the very extensive literature published by the Swiss and the Americans during the last decade.

Lieut.-Commdr. J. CORTLANDT-SIMPSON, R.N.: Is it possible that by erecting a measuring gauge on a pylon, say 100 ft. high, one could get above the level of drifting snow, and so obtain measurements of precipitating snow? If during drift conditions the snow collected at different heights above a flat surface (for example the ice shelf) could be measured, it might be possible to work out a theory on the variation of drift with height. Measurements then made during simultaneous precipitation and drift conditions, if taken at various heights, might be capable of extrapolation to give the amount of snow falling due to precipitation only, which is what we most need to know.

Dr. BROOKS: The difficulty could not be overcome in this manner because eddies round the gauge would reduce the catch by a large but unknown quantity. The best way of obtaining measurements is to measure the accretion of snow on a large flat surface.

Mr. A. STEPHENSON: May I stress the importance of synchronizing meteorological observations. Data obtained, say, during a single blizzard at a single point might be entirely valueless, whereas if observations were made at the same time at other places much information might be made available.

3. *Frequency of surface hoar, rime and depth hour. Rates and methods of growth. Crystal structure*

Mr. J. M. WORDIE: There might be an opportunity to study precipitation in the form of rime in the South Orkneys, where a permanent station has been set up by the Falkland Islands Dependencies Survey. One of the features of the South Orkneys, and this may also be the case in the South Shetlands, is the presence of rime in quantities on the high peaks, which gives them a characteristic steep appearance seen from a distance.

4. *Shapes and sizes of snowflakes and their connection with meteorological conditions*

Mr. BONACINA (communicated): I notice every winter in England that different snowfalls tend to produce different types of crystals and that by no means all, or even most, yield mixed or variegated forms. The correlation of this fact with meteorological and climatic conditions is obviously suggested and attention should be given to the matter in the Antarctic. It is, perhaps, apt to be forgotten that even in temperate climates it is normal for snow to fall in pure crystals, so long, that is to say, that it is pure dry snow and not wet, flaky sleet.

Mr. SELIGMAN: For a long time I have been anxious to follow the line suggested by Bentley that varying meteorological conditions give rise to a characteristic shape of snow crystal. I very much hope that research in this direction can be continued. Nakaya and others have done work on this subject under laboratory conditions.

Mr. G. MANLEY: Vincent Schaefer has done important work in fixing snowflakes by forming tiny castings of a resin around them. The ice is then melted away and the case remains, so that the crystal shapes can be examined at leisure. (Cf. *Nature*, Vol. 149, 1942, p. 81. *Natural History*, Vol. 51, 1943, pp. 20-27.)

5. *Snow temperatures. Relationship with air temperatures*

Mr. DOBBIE: We would be glad of any information on the technique of measuring the temperature distribution with depth in the snow (bore holes) and the surface temperature.

Mr. SELIGMAN: Professor F. Alton Wade devised a very excellent way of measuring snow temperatures on the U.S. Antarctic Service Expedition, 1939-41. Details are being published in the *Journal of Glaciology* (ref. Vol 1, No. 2, 1947, p. 73).

6. *Change of snow to ice (if any) in a stationary snow cover. Comparison between crystal structure of such ice and glacier ice*

Mr. BONACINA (communicated): This item arose from a remark I made recently to Mr. Seligman that during the recent winter I used to find myself walking on hard ice in the very streets and parks of London as the older snowfalls became consolidated beneath the later fresh snow. I used to nickname this glacier ice; but I cannot suggest how much of it was due to the hardening effects of traffic in the sub-freezing temperatures which prevailed and how much to freezing after the occasional partial, temporary thaws.

Mr. SELIGMAN: In connection with work that Mr. I. R. Menzies is going to do this summer in Iceland, the change of snow into ice by the thaw-freeze process, regarded from the crystallographic point of view, might give interesting results.

Mr. J. E. FISHER (New York, communicated): Have any of the speakers come across "snow swamps" in the Antarctic or Arctic during the summer, *i.e.* the snowfields where melt water accumulates as soggy or slushy snow over a period of days or weeks, and if so could he mention the approximate area of such snow swamp and its location and altitude?

Professor F. DEBENHAM: Anywhere near sea-level, particularly on lakes, you are liable to get snow so damp that it is practically a swamp.

Dr. N. E. ODELL: In the lower glacierized tracts of Spitsbergen a mixture of water and slushy snow are often to be found in the height of summer in areas of internal drainage amounting to many acres in extent (glacier morasses). As Mr. Matthes has pointed out, sun cup and ploughshare structures in regions of low humidity and low temperature point to the fact that no run-off of the melt water is to be expected.

B. GLACIERS (GENERAL)

1. *The occurrence of various glacier types in the Antarctic*

Mr. SELIGMAN explained that this referred to the morphological features of glaciers, valley (alpine type) glaciers, ice caps, outflow glaciers, etc.

Mr. WORDIE expressed doubt as to the existence of "strand flat glaciers" as suggested by Professor Holtedahl along the Graham Land coast. Glaciers of this type were more apparent than real. The British Graham Land Expedition suggested "fringing glaciers" as a more appropriate title. At localities such as the Argentine Islands, where the amount of ice was small, there was no feature on the bare land which could be described as a "strand flat" and yet the ice faces present suggested that they were lying on a raised beach and gave a wrong impression of the nature of the bare rock below the ice covering.

The CHAIRMAN said that some study had been made of Holtedahl's strand flat glaciers during the British Graham Land Expedition, but the name "fringing glaciers" seemed more appropriate. These glaciers and the peculiar ice caps near the coast evidently originated at a time when they were continuous with an extensive sheet of coastal shelf ice and they were thus relic glacial forms. It was significant that along the west coast of Graham Land fringing glaciers rest on benches at sea-level, but, so far as could be ascertained, there was little morainic material in the bottom of the ice. It was not at all clear, therefore, whether the fringing glaciers had excavated the platforms on which they rested. Further investigation was needed to determine the detailed characteristics of fringing glaciers and the nature and morphology of the sub-glacial terrain. The results of such work might throw light on the origin of strand flats.

2. *Nature of glacial erosions (contemporaneous action, see F. 2 below)*

Dr. ODELL, Dr. M. F. PERUTZ and other speakers referred to the results obtained by Dr. H. Carol (*Die Alpen*, 1943, pp. 173-80 and *Journal of Glaciology*, Vol. 1, Nos. 1 and 2, 1947), by penetration to the glacier bed through glacier mills and marginal crevasses. Where conditions were favourable this method promised far-reaching results.

Dr. PERUTZ thought that exploration of the glacier bed by working along the bed of the glacier stream during the winter when melt water was at its minimum would also give valuable information.

Dr. J. N. CARRUTHERS (Oceanographer to the Hydrographer of the Royal Navy) referred to a considerable amount of work that had been done in this manner many years ago and reported in the *Glacialists Magazine*, a publication now discontinued.

The CHAIRMAN pointed out that valuable as the method would be in temperate, and perhaps in certain northern, regions, glacier streams of any appreciable size would, if present at all, be rare in the Antarctic.

3. *Investigations of moraines, their petrology, etc.*

No comments.

4. *Melt-water tunnels*

Mr. W. V. LEWIS said that efforts should be made to determine the depth of penetration of melt-water tunnels by direct exploration and other means. Fluorescein might help the courses of melt-water streams to be traced. The discharge of these streams should be measured "day" and "night" during cold and warm spells and during summer and winter.

5. *Glacier tongues*

Professor F. DEBENHAM thought that insufficient attention had as yet been paid to the special form, common in the Antarctic, though rare elsewhere, namely the glacier tongue, that part of a coast-line glacier which is afloat. The glacier tongues were very accessible, they were of all sizes and exhibited several strange features such as having a rate of movement much greater than land glaciers. In some respects they could be considered as intermediate between the true land ice masses and true shelf ice. He strongly recommended special attention being given to the conditions of temperature and of ice accretion by freezing underneath glacier tongues and small shelf ice formations, conditions which must be closely concerned with their growth and permanence.

6. *The length, breadth and depth of the Antarctic glaciers*

7. *The presence of extrusion flow; effects of temperature on extrusion flow and depth of crevassing*

8. *Measurements of stresses inside glaciers and of surface flow rates*

9. *Records of speed and intermittent flow*
10. *Relative extents of "grain flow," plastic flow and block flow*
11. *Crystal growth and orientation in all parts of glacier for comparison with temperate glaciers*
12. *Frequency of true ice (sp. gr. 0.82 and greater)*
13. *Glacier banding*
14. *Firn waves*
15. *Glacier temperatures; relationship with air temperatures; relationship with temperate glaciers and the Greenland ice cap*

Dr. PERUTZ pointed out that items 6 to 15 above, although entered as separate headings in the list of subjects sent to members, came under the general heading of "The Mechanism of Glacier Flow."

He said: The Glacier Physics Committee is particularly interested in this question and on their behalf I should like to make a plea for a thorough investigation of *one* typical Antarctic glacier. It is our object, ultimately, to formulate a satisfactory theory of glacier flow which covers the peculiarities both of temperate and polar glaciers. Great efforts are now being made both by ourselves and by our Swiss colleagues (with whom we are now in close contact) to collect the necessary experimental data for a temperate glacier. It would be very helpful if corresponding data for a polar glacier became available. The most important measurements for this purpose are the following:

(a) *Determination of surface velocity over a longitudinal, and at least one transverse, profile, if possible throughout the year.*

(b) *Determination of glacier depth in these profiles by seismic methods.*

(c) *Measurement of vertical temperature distribution in these profiles.*

This might be called the basic programme. Much other useful and interesting work could be done; its feasibility would depend largely on the membership of the expedition and the instruments at their disposal. In my view the following points would merit investigation:

(d) *Measurement of differential flow at selected points in the ice region, coupled with a study of crystal orientation.* This should provide information on the micro-mechanism of flow in solid ice (density above 0.82) at temperatures below the freezing point, as opposed to the corresponding mechanism at the melting point prevalent in alpine glaciers. Corresponding measurements in the snow or firn region are probably superfluous, since there is no reason to suppose that the mechanism of flow would be different from that found by Seligman and myself on the Jungfraufirn. Research on crystal growth, orientation and the mechanism of ice formation could follow the lines indicated by the Jungfraujoch Research Party, 1938. Particular attention should, however, be paid to the mechanism of crystal growth in the absence of melting.

(e) *Correlation between differential flow and banding.* If observations indicate that certain bands in the glacier constitute large-scale thrust planes, the velocity of shear in the thrust plane and the crystal orientation should be determined.

(f) *Correlation between ice temperature and depth of crevasses.* Since the plasticity of ice decreases rapidly with falling temperature, one would expect the maximum depth of crevasses in the Antarctic to be much greater than in the Alps, where it is of the order of 35 m.

(g) *Measurements of differential flow and stresses at great depth and of intermittent surface flow.* This will have to await the development of satisfactory techniques on Alpine glaciers, upon which we are at present engaged.

Dr. ODELL and other speakers said there was little doubt that in polar glaciers the crevasses were deeper than in temperate glaciers. Dr. Odell pointed out that this was in conformity with the extrusion flow hypothesis. It was also of practical importance.

Mr. W. H. WARD observed that in reference to item (g) above he did not know how it was proposed to measure the stresses inside glaciers, but the variation of horizontal stress with depth should be determined. The technique used for measuring the variation of lateral earth pressure with depth in pits and trenches might be used. The method was to measure the strains in the trench strutting by means of gauges. The load in each strut could then be estimated from its stress-strain characteristics and the lateral pressure distribution determined. The yield of the strut and the yield of the ice, which was unavoidable in the course of placing the strut, might well modify the magnitude of the lateral pressure and this fact required investigation.

Several speakers urged the necessity of concentrating research of the kind advocated by Dr. Perutz upon a single typical glacier, rather than of obtaining isolated data on a number of glaciers.

16. *Photogrammetric recording of glacier speed and intermittent flow*

Professor C. A. HART (University College, London): I agree that it would be essential for any modern Antarctic expedition to make use of photogrammetry. This can be employed in one or both of two ways:

(a) *Air photogrammetry.* This would involve periodical vertical stereoscopic photography, the taking of which would depend upon weather and light conditions. It would clearly be necessary to photograph the same area time and time again, and to ensure that ground control marks outside the area of movement were identifiable on the photographs. Such ground marks must be of appreciable size and of distinctive shape to allow of identification; their maintenance might present some problems.

It would also be necessary to ensure that the navigation to the area photographed was accurate. This would need either clearly defined land marks or navigational guidance.

The recording of movement would depend upon the scale of photography, and the rate of movement of the glacier. Thus for photographs taken from a height of 5000 ft. (1524 m.) with a lens of 6 in. focal length, the scale would be 1/10,000 or 0.1 mm. to 1 m. If this were used for photography of a glacier moving at the rate of 80 m. per annum, this would represent 0.7 mm. of movement on the photograph per month. Accurate rectification of the photographs would eliminate height and tilt distortions, but the accuracy of determination of movement might well be lost by reason of film and processing distortions.

(b) *Ground photogrammetry.* The photography at fairly short range by photo-theodolite or by a pair of short-base photogrammetric cameras would, I think, provide a much more satisfactory local result, although the air method can give a very good general "picture." The short-base method in particular is promising, with its fixed base and fixed relative direction of the pair of photographs. The necessary plotting apparatus for such work will be installed at University College London within the next year or so, and I should be delighted to make it available for analysis of any such photographs taken during an expedition.

Mr. A. STEPHENSON: In connection with the use of air photographs for measurements and identification of features on glaciers, I would strongly recommend that an attempt be made to obtain data similar to those required from existing photographs of glaciers in Switzerland. There are various problems of measurement and identification which may be much easier to solve in certain light conditions and on a particular scale. A great deal of time may thus be saved in the field if the photographer can be given precise requirements as to the most suitable scale, light conditions, direction of photography, etc., for a particular problem.

C. GLACIERS (CLIMATOLOGICAL)

1. *Glacier regime and fluctuation*

Mr. SELIGMAN referred to the work which Professor Ahlmann had already carried out in many parts of the northern hemisphere. Details were fully recorded in his many publications and it was to be hoped that the technique of this valuable climatological survey would be learnt and the work continued by British glaciologists and others at every opportunity in all glacierized regions.

2. *Position of Antarctic glaciers in the glacial cycle*

Dr. BROOKS said that one of the problems of the Quaternary was the determination of the succession of events in the Antarctic and especially whether this ran parallel with that in the northern hemisphere. This had a great bearing on the whole problem of the causes of ice ages, but it was likely to be difficult. It was too much to hope for the discovery of a long series of banded clays, since the conditions for their formation were absent, but the possibility of a closer determination in some other way should be borne in mind. In the sub-Antarctic islands the detailed microscopical examination of peat deposits might throw some light on the late-glacial climatic change.

Mr. SELIGMAN asked whether there was a possibility that the spores of cryptogams might take the place of pollen, analyses of which had given very instructive results in temperate glaciers.

Mr. MANLEY said that the rate at which deposits had been laid down on the ocean bed might give some idea of the recent retreat of the Antarctic ice. He imagined, however, that it was a geological problem to determine at what time the Antarctic ice cap had been formed.

Mr. J. R. F. JOYCE said that it was possible that information as to the advance of the Antarctic ice might be obtained from the Pecten Conglomerate of Cockburn Island, northern Graham Land. This formation was of Pliocene age, but no *Ostrea*, a warmth-loving genus, had been found in it. With regard to the northern extension of the ice during Quaternary times, examination of the pollens of peat beds in the Falkland Islands and on the South American continent might provide some evidence.

3. *Past glaciations*

No comments.

4. *General comments on glaciers (climatological)*

Mr. MANLEY asked to be allowed to combine the remarks he might otherwise have made under different headings as, in the main, climatological questions were involved. Measurement of precipitation on the ice cap was most desirable. Take for example the invaluable contribution of the Wegener party at Eismitte and their determination of a water equivalent of 12 in. (30.4 cm.) per annum. Similar work would greatly help in the elucidation of Antarctic meteorology. Radiation balance at high levels should also be studied; there was Ahlmann's challenging view that above 7000 ft. (2133 m.) in Greenland radiation was virtually the sole agency in ablation. Evaporation was probably slight as the air was always very near saturation. That the glaciers were retreating at low levels was well known, but the decrease of thickness at high levels recently shown by the 1939 German flights and the resulting photographic survey made in the Norwegian sector needed much study.* Bare ground at high levels with small but detached frozen lakes at 6000 ft. (1829 m.) could be interpreted as indicating a considerable decrease in thickness of ice, presumably largely due to reduced precipitation, followed, nevertheless, by increased cold. It was difficult to envisage the needful amount of thawing at high levels in the Antarctic to produce lakes under present

* References summarized in Manley, G., *Q. Journ. R. Met. Soc.*, Vol. 72, No. 314, October 1946, p. 317.

climatic conditions; whether thaws occurred, and if so, how, was a fascinating problem for the meteorologist to which the glaciologist might well contribute. Precipitation and ablation should obviously be studied at the highest points of the ice cap, though this would be no easy matter at 15,000 ft. (4572 m.). We were still very ignorant of the external dimensions of the ice cap and its age. Contouring by aircraft fitted with radar might give at least a first approximation.

Regarding the age of the ice cap, Mr. Manley said that he was reminded of Wager's interesting view that that of Greenland might be far older than the Pleistocene. As regards retreat stages, the high-level moraines in the Norwegian sector would no doubt repay study, and the alimentation of small mountain glaciers above the present level of the ice cap also offered an interesting problem.

Dr. ODELL thought that the seismic sounding of glaciers referred to above should also be carried out in connection with ice sheets. Also that there should be, so far as possible, bathymetric sounding and sampling along the continental shelf for evidence of submarine cañons, etc.

D. SHELF ICE

1. *Structure and mechanics*
2. *Origin of ice shelf—glaciers or snow field?*
3. *Movement. Regime above and below. Depth. Mapping of ice edge for record*
4. *Temperature and salinity of water below shelf*
5. *Crystal size and growth*
6. *Temperatures in ice shelf*

A general discussion under these headings showed that there was no new problem and that the lines of any research should be similar to those proposed for Professor F. Alton Wade for the U.S. Antarctic Service Expedition, 1939-41. Professor Wade's work was interrupted by the war, but the results obtained by him are to be found in *Proc. American Philosophical Society*, Vol. 89, No. 1, 1945, pp. 160-73. (See also *Journal of Glaciology*, Vol. 1, No. 1, 1947, pp. 23-31.)

The question of boring, however, was further considered:

Dr. G. C. L. BERTRAM said that the ability to bore easily into ice was clearly a matter of great importance. He urged that mechanical devices should be developed to take the place of the arduous manual exertions of Seligman and others. The American machinery for the rapid placing of fencing posts might be a basis for the evolution of efficient plant.

On the suggestion of Mr. Dobbie that heat boring might be suitable:

Mr. SELIGMAN said that he was awaiting details of a heat boring tool from the Canadian Snow Research Station under Professor R. F. Legget of Toronto. He feared, however, that this might prove too cumbersome. The problem of quick, light boring apparatus was of fundamental importance in glacier and ice research to-day. The Glacier Physics Committee was engaged in finding the best method of doing this and he knew that if any new technique should come to light, they would be very glad to hear of it.

Mr. WARD said that the development and mechanization of deep-boring equipment was rather backward in this country and much of it had remained unchanged for perhaps a century. He was interested in the development of light mobile boring equipment, and at the moment he was experimenting with some light alloy boring rods. If he could give the Glacier Physics Committee any help in this direction he would be pleased to do so.

E. SEA ICE

1. *General features of pack ice in the Southern Ocean, including seasonal changes, movements, etc.*

Dr. N. A. MACKINTOSH (communicated): Research on pack ice has an important bearing on oceanography, meteorology and navigation, and I think information is needed on the broad features of its seasonal distribution around the Antarctic, on the rate and direction of its drift and on the processes of its formation and disintegration.

The mean positions of the ice edge are known approximately in a large part of the Antarctic in the summer months, though data for the winter months (and for all months in the Pacific sector) are inadequate. It seems to me that information is specially needed on the proportion of ice and open leads, the size and type of floes, etc., in the pack ice belt as a whole, and on the occurrence of extensive areas of open water between the ice belt and the continent. Probably very few data can be obtained without observations from the air, and it may be that the recent American naval expedition will contribute useful information. From accumulated observations of this kind it may be possible eventually to make a rough estimate of the total area covered by pack ice at different times of year. Such data, considered together with information on the distribution of different types of floes and their thickness and density, might ultimately contribute to an estimate of the volume of cold water released annually by the melting ice. Observations of this kind should in any case be of value in their bearing on navigation and access to the continent.

The drift of the pack is presumably controlled mainly by the prevailing winds, but actual measurement of the drift of a large body of pack might be difficult. Perhaps changes in the distribution of ice in a given area, observed during periodic flights, might indicate at least the local direction of drift, or planes might drop marks of some kind on to large floes.

2. *Local distribution of the pack ice*

Dr. MACKINTOSH (communicated): I should suggest that it is always worth while for an Antarctic expedition to keep full records of the local distribution of sea ice so far as it can be observed, including its changes throughout the year if possible. Such records may have a limited significance, but they are naturally of value to subsequent expeditions.

Dr. BROOKS pointed out that the Marine Branch of the Meteorological Office had already a large collection of data on the position of the edge of the pack in Antarctic waters and would welcome any further observations, both from air surveys over large areas and from ships' observations. The data were of great importance to shipping and were used to construct average maps of limits and variations from time to time.

Mr. WORDIE and Mr. STEPHENSON commented on the difficulty of mapping the pack ice edge owing to its continual change and thought that the many month to month boundaries would have to be omitted for the sake of clarity.

3. *Formation and disintegration of the pack, including types of ice floes; physical investigation on their life history. Freezing of the sea; ice forms*

Mr. SELIGMAN said that a great deal of work had already been done on this subject by glaciologists of many lands and, at any rate so far as the last of these headings was concerned, it might be that there was not a great deal of further research to be done that would be profitable at the moment.

4. *Life history of icebergs. "Névé bergs" of Wright and Priestley; their impregnation by sea or melt water*

Dr. MACKINTOSH (communicated): So far as I know there is very little information on the period between the calving of an Antarctic iceberg and its ultimate disappearance, and any data

bearing on this problem should be useful. If an iceberg, likely to drift through the region visited by many whaling factories, could be marked or identified in some way, there might be a chance of following some part of its history. Measurement of the speed and direction of the drift of an iceberg even over a short distance would be a useful indication of the local current movement. For example, a plane making periodic seaward flights from a base on the continental coast might not only observe changes in the distribution of pack ice but might also drop marks on a few bergs and obtain some measurement of their rate of drift.

Mobile expeditions such as those of the Discovery Committee and Byrd's recent expedition are in the best position to obtain data on the general distribution of pack ice and icebergs; but land expeditions which can keep a limited coastal area under observation through the seasons, can clearly do valuable work, especially if aircraft are available, apart from any research which may be possible on the physics of sea ice.

Mr. WORDIE asked if by "*névé* bergs" was meant "tabular or barrier bergs." A large number of barrier bergs of great size had drifted out of the Weddell Sea in the early 1930's. Why this was so had always been a problem, but after seeing the effects of the tidal wave last April in Graham Land he thought that a catastrophe of this nature had been responsible for the formation of the great tabular bergs. Should this be so one might expect a further number to be broken off in the near future and to drift out in due course to lower latitudes.

Mr. SELIGMAN said that by *névé* bergs he understood a berg that was composed of porous snow or firn, irrespective of from where it had come. He hazarded the guess that such bergs absorbing sea water by capillarity would gradually change into bergs of solid ice.

5. *Inclusion of land ice in icebergs*

No comments.

6. *The ice foot*

No comments.

7. *Relationship of land and sea ice to meteorological and oceanographical conditions*

Dr. BROOKS thought that this was hardly a subject for research by an expedition, but was undoubtedly worth investigation. There was a relation between ice conditions in the Arctic waters and the weather of northern Europe, and it was probable that there was also a relation between the area of Antarctic pack and the weather of South Africa, Australia and New Zealand.

F. GLACIAL GEOMORPHOLOGY.

1. *Glacial characteristics of any bare ground or prominent feature*

2. *Past erosion (see B. 2 above)*

3. *Roches moutonnées*

4. *Frequency of en- or sub-glacial material*

5. *Morphological evidence of past glaciations. Evolution of nivation hollow to multiple cirque. Present erosion in cirques*

There were no detailed comments under the above headings. In a general discussion which followed:

Mr. LEWIS said that snow patches might be examined to determine whether or not they were removing fine material from the hollows they occupy. The head and side walls of cirques might be examined to ascertain if cirque erosion was still active. Attempts might be made to trace, by photograph and map, a sequence of forms from nivation hollow to cirque. Ice-rock contacts would repay examination wherever they occurred, with a view to learning something of the nature and

degree of glacial erosion. Striations indicating extrusion flow might also be looked for in areas from which the glaciers had receded. Moraines could be examined to determine whether or not such retreat was in progress.

Dr. ODELL urged that there should be a close examination of the flanks of mountains which rise above the ice sheets for evidence of past submergence. There might also be evidence of former bergschrunds and other features of existing glaciers.

Mr. MANLEY suggested that attention should be given to the high-level moraines mentioned by Professor Ahlmann as these might give data of value in this matter.

Dr. BROOKS said that in addition to morphological evidence of past glaciations it would be desirable to look for evidence of running water.

Mr. WARD suggested that the retreat of glaciers could probably be revealed by observations of ground temperatures in the neighbourhood of glacier snouts. Underneath the glacier the ground would be warm due to the insulation of the ice, whereas in front of the glacier it would be colder. The rate of depression of the deep ground isothermals would lag considerably behind the retreat of the ice. Thus observations of ground temperatures might reveal the past history of ice movements.

G. GENERAL

1. *Mapping of ice caps, glaciers and ice shelves by aircraft*

The CHAIRMAN reminded the meeting that this subject had been dealt with earlier in the discussion and asked whether there were any further comments of a general nature.

Mr. DOBBIE (communicated): As you may be aware, Australia is at present closely concerned with Antarctic research in connection with a projected expedition to those regions. Mr. C. H. B. Priestley, Officer in charge of Meteorological research, indicates that the plans for research do not include glaciological work *per se*. He writes:

In the first instance we shall be mainly concerned with the large-scale phenomena, the air circulation of the regions and the accompanying pressure, temperature, moisture, etc., interchanges. It is hoped that it will be possible to introduce more special and local investigations at a later stage. Some of these will be closely related to items on the Glaciological Society's list, particularly Section A. They include measurement of humidity in the surface layers, adjustment of air conditions to the underlying surface, transfer of heat between air and snow (by radiation, conduction and turbulence), precipitation, sublimation and evaporation, types of falling snow, etc.

As there is no plan to include a glaciologist in the party * the other scientists would probably welcome advice if there is any way in which observations useful to the glaciologist can be taken without over-elaborate preparations or the need of specialized knowledge. As we may very likely occupy the station over a period of years there is obviously a unique opportunity here.

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At the conclusion of the meeting the CHAIRMAN referred to the paucity of trained glaciologists. It was important to encourage men who would be competent to carry out some of the many suggestions for research which had been made. It was encouraging to hear of the work of the Glacier Physics Committee.

He thanked Professor Debenham for the use of the Geographical School and the excellent arrangements which had been made. He also thanked those who had contributed to the discussion. Finally he said how glad the Society was to welcome so many members of the University at the meeting.

* See note on p. 147.